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DOMINANTLY FLUVIATILE ORIGIN UNDER SEASONAL
RAINFALL OF THE OLD RED SANDSTONE

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The Devonian system is represented in the British Isles by a series of rocks many thousands of feet in thickness, none of which, except in the south of England, hold marine fossils. Red sandstones constitute the predominant exposures, the colors ranging from light red to deep chocolate-brown, but in places are also found sandstones and shales of green, gray, or yellow colors. Besides the sandstone, the system includes much shale and conglomerate, the latter in places consisting of large-sized and subangular *débris*. Much volcanic material is intermixed in certain localities. This system of rocks, so distinct from the marine formations, has been familiarly known since the days of Hugh Miller as the Old Red Sandstone.

The sediments are mostly barren of organic remains, but at certain horizons many fossils have been found,—plant fragments, *estheria*, scorpions, myriopods, eurypterids, ostracoderms, and fishes. Several distinct faunas are found, representing successive epochs. These fossil faunas contain the oldest known ganoid fishes and the oldest well preserved representatives of those primitive and spinose sharks,—the *acanthodeans*. Ostracoderms are well represented also. In contrast to this abundant preservation of chordates in certain horizons of the Old Red Sandstone, the rocks of earlier geologic periods show only rare and usually fragmentary remains belonging to this phylum.

Our own ancestral line is regarded as having ascended through *elasmobranchs* and *crossopterygian* ganoids. These groups evidently flourished at the time of the Devonian period within the environment under which the sediments of the Old Red Sandstone were laid down. If, then, we can determine the conditions of origin of those sediments we shall restore by so doing the life surroundings of the primitive ancestral vertebrates; life surroundings which were related to their passage from the realm of the waters to that of the land and air.

Godwin-Austen, noting the distinctness of the Old Red Sandstone formations from the typical marine Devonian, was led to a view in 1855, previously maintained by Dr. John Fleming, that the sediments were laid down in great freshwater lakes or inland seas. This interpretation rapidly supplanted the older view advocated by Hugh Miller, that the Old Red Sandstone was of marine origin. This lacustrine interpreta-

tion prevails in British opinion to the present day, though it is true that Macnair and Reid¹ reverted in 1896 to the hypothesis of marine origin, and Goodchild in 1904,² pressing in the other direction, urged "that the whole of this vast formation was accumulated under continental conditions, partly in large inland lakes, partly as torrential deposits, partly as old desert sands, and partly as the result of extensive volcanic action." In 1908 Walther published a volume which consisted of a general review of historical geology. In the section touching on the Old Red Sandstone, he held that the lakes of the British geologists were in reality desert basins which "possessed a hot desert climate whose dry periods were broken only seldom by the downpour of thunder storms."³

In other places Kayser and Walther have expressed the view that the Old Red Sandstones were deposited in lagoons not far from the sea, the water being thought of as occasionally replenished by the sea and the deposition as taking place in lagoons and as dunes on their margins.

Thus we see that a great variety of conclusions, amounting in fact to flat contradictions, have been expressed and are still entertained by geologists in regard to the nature of the habitat of the early vertebrate faunas whose remains are found in the formations of the Old Red Sandstone. Yet this is to the geologist and biologist a most important problem, especially as it may be shown that the conditions of the environment held important causal relations to the rise of amphibians.

The differences in conclusions are not due to differences of opinion in regard to the actual facts of stratigraphy, but to radical differences in the interpretation of those facts. At the present stage of investigation it is of the first importance therefore to determine the criteria for interpretation and their degree of validity. It is that subject especially to which the writer has given attention in previous investigations. The present conclusions rest therefore upon the following papers.

In November, 1906, the writer, introduced by Professor Davis, gave a paper before the National Academy of Sciences entitled 'Continental Sedimentation with Applications to Geological Climates and Geography.' The articles on this general subject were published *in extenso* in the *Journal of Geology* in 1906 and 1908.⁴ In 1913 and 1914 articles were published in the *American Journal of Science* on the formations in the eastern United States which correspond to the Old Red Sandstone system of the British Isles.⁵ In the present article, therefore, the establishment of the criteria on which the conclusions rest may be omitted and the resulting interpretation directly given.⁶

This interpretation leads to the conclusion that the deposits which make up the Old Red Sandstone, although they undoubtedly contain

lacustrine beds and other beds laid down in shifting, shallow, and variable bodies of water, are dominantly fluvial in origin; laid down over river flood plains by streams in times of flood, exposed to air in times of drought. They record in this way the existence of an alternation of seasons of rainfall and drought—a climate with an arid season, but not an arid climate. This type of climate is best defined as semi-arid, and is existent over broad areas at present, especially in much of the torrid zone. Such a climate is to be sharply distinguished in thought, on the one hand, from that of a typically humid character, such as now prevails in northwestern Europe and northeastern North America; and, on the other hand, from truly desert climates, such as prevail in central Asia or northern Africa. The conclusion as to dominantly fluvial origin,—similar to the mode of origin of the sediments now accumulating within the Great Valley of California, or on the Plains of Mesopotamia, is also to be sharply distinguished from the conception of great and permanent lakes, as well as from the opposite conception of torrential and eolian conditions in desert basins. Thus the present interpretation is distinctly different, both in regard to climatic and physiographic conditions of origin, from either the prevailing British or the German conceptions, but approaches nearest to that given by Goodchild.

The character of this interpretation may be called American, for in its main lines the writer does not stand alone. W. M. Davis, Hatcher, and others have shown the general importance of flood plain deposition. Especially may be mentioned the work of Grabau who has independently reached similar conclusions in regard to the importance in certain Paleozoic formations of fluvial deposition. He has studied the Old Red Sandstone in the field and, though he has not published on that subject, has publicly stated that his conclusions are the same as those here expressed. More recently Schuchert has reviewed the evidence and expresses similar conclusions, though the part played by rivers as distinct from lakes is not so sharply differentiated as in the papers of Grabau and the writer.⁷

In closing we may draw a picture of the geography of Great Britain in Lower Devonian times. The region was then a part of a continent which extended an unknown distance northward and westward. Beyond the northwestern side of Great Britain extended a mountain system. The region of Great Britain was, in this newer interpretation, made up of a sequence of river basins separated by minor ranges of mountains, the whole marginal to the greater mountain system. Sediment was brought into these basins by rivers from the bordering uplands and from the more distant regions to the northwest. The excess

beyond what was laid down by the rivers in time of flood to maintain their grade across the sinking basins was carried through to the shallow sea which lay on the surface of the continent to the southwest. The relations were somewhat similar to those which now prevail between the ranges of the North American Cordillera and the Tertiary basins which lay between them and especially on the west between the Sierra Cascade chains and the Coast Ranges. The Great Valley of California may therefore in the present epoch, both in physiography and in climate be cited as a striking illustration of the nature of the Old Red Sandstone basins.

¹ Macnair and Reid, *Geol. Mag. Decade IV*, 3, 106-116, 217-221 (1896).

² Goodchild, J. G., The Older Deutozoic Rocks of North Britain, *Geol. Mag. Decade V*, 1, 591-602 (1904).

³ Walther, J., *Geschichte der Erde und des Lebens*, 259 (1908).

⁴ Barrell, J., Relative Geological Importance of Continental, Littoral, and Marine Sedimentation, *J. Geol.*, 14, 316-356, 430-457, 524-568 (1906); Relations Between Climate and Terrestrial Deposits, *Ibid.*, 16, 159-190, 255-295, 363-384 (1908).

⁵ Barrell, J., The Upper Devonian Delta of the Appalachian Geosyncline, *Amer. J. Sci.*, 36, 429-472 (1913), 37, 87-109, 225-253 (1914).

⁶ This paper was given in brief form at the meeting of the American Society of Vertebrate Paleontology at New Haven, Conn., on December 26, 1907 [Loomis, F. B., Report of the Secretary, The American Society of Vertebrate Paleontology, *Science*, 27, 254 (1908)], and more fully at the meeting of the Geological Society of America at Washington, December 28, 1915. It will be published in full in the *Bulletin of the Geological Society of America* in 1916. The present paper is a digest and its chief importance is because of its bearing on the environment of early vertebrates. In that way it is introductory to a paper on the Influence of Silurian-Devonian Climates on the Rise of Air-breathing Vertebrates which will follow in these PROCEEDINGS.

⁷ Pirsson-Schuchert, *Text Book of Geology*, Part II, *Historical Geology*, by C. Schuchert, 714-721 (1915).

THE INFLUENCE OF SILURIAN-DEVONIAN CLIMATES ON THE RISE OF AIR-BREATHING VERTEBRATES

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The problems of organic evolution have many aspects and ramify into many fields of science. The subject was at first embraced chiefly in the domain of the old time naturalist—zoologist or botanist. But the problems of variation and heredity have passed into the hands of the experimental evolutionist; and there are other problems whose answers are found in the geologic record—but these are of two rather opposite aspects. On the one hand, the paleontologist specializes particularly